Haptics and Directional Audio Using Acoustic Metasurfaces

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Abstract

The ability to control acoustic fields offers many possible applications in loudspeaker design, ultrasound imaging, medical therapy, and acoustic levitation. Sound waves are currently shaped using phased array systems, even though the complex electronics required are expensive and hinder widespread use. Here we show how to control, direct, and manipulate sound using 2-dimensional, planar, acoustic metasurfaces that require only one driving signal. This offers the advantages of ease of use and versatility over currently available phased arrays. We demonstrate the creation of a haptic sensation and steering of a beam produced by a parametric speaker. This simple, yet highly effective, method of creating single-beam manipulators could be introduced in medical or manufacturing applications.

Author Keywords

Metamaterials; 3D Printing; Haptic; Sound

ACM Classification Keywords

H.5.2 [Haptic I/O]; H.5.1 [Audio input/output]

Introduction

Sound waves travel unhindered on a straight path in free space; this path can be curved through reflection, refraction or diffraction. The phasing effects between two or more interacting waves are rigorously exploited in ultrasound imaging common in medical diagnostics and non-destructive evaluation of materials.

Phase is a result of offsetting a signal in time and has been used to describe transmissive line behaviour since the 19th century. Specific, or programmable time delays using multipath structures are in widespread use in phased arrays for radar and ultrasonic systems. Phased arrays usually consist of a series of individual elements, each with its own connector, time delay circuit, and analogue-to-digital convertor. Traditionally, the time delay can be accomplished either optically or electronically. Both methods allow control of the amplitude and phase of each element, which enables fine manipulation of the beam direction and shape, and can be changed more rapidly than a mechanically handled array. Here we exploit an acoustic alternative in order to reduce their operation complexity, making them more deployable and ubiquitous.

The recent implementation of acoustic metamaterial bricks [3] as engineered blocks of matter has enabled a plethora of potential functionalities, including beam steering, lensing, and holography. The brick design essentially forces sound waves to propagate through air meanders that are much longer than their external dimension. By adjusting the total length of the meander, the apparent phase can be effectively tuned (up to 2π). The bricks can be assembled into 2D planar metasurfaces to generate any diffraction-limited acoustic field. The resulting surfaces essentially emulate the functionality of an active phased array, but without any complicated setup or operational procedures.

We demonstrate the versatility of acoustic metasurfaces that require only one driving signal in two applications: a tactile display enabling haptic feedback and the steering of a beam generated by a parametric speaker. Both demos manipulate airborne ultrasound, but at different frequencies and creating different effects.

Haptic Demonstation

Context

A popular way to create mid-air haptic feedback is by using a phased array of ultrasonic speakers [1, 2]. Ultrahaptics does this by focusing its array of ultrasonic speakers (operating at 40kHz) on a point of the user's skin and modulating this at different, lower frequencies. Typically the device consists of many speakers, each of which is individually controlled to shape the acoustic field. This focal point contains enough force to slightly displace the surface of the skin, which the user registers as touch. Typically the Ultrahaptics board is used in conjunction with a hand tracking device to keep the focal point 'attached' to a place on the users hand.

Procedure

Using a phased array for haptic feedback requires precision timing and control of individual speakers. This limits scalability of the system. In this demonstration we instead use speakers that are all turned on and off at the same time and shape the emitting acoustic pattern through our metasurface by introducing a unique time delay with each metamaterial brick. The resulting plane wave is then modulated at 200Hz from it's carrier signal of 40kHz, as human skin can only sense pressure changes below 1kHz. Once the metasurface lens is placed over the array, a sub-wavelength focus is created at a chosen height. While there are some random sensations created from the array alone, there is an immediately noticeable effect when the metasurface is added.

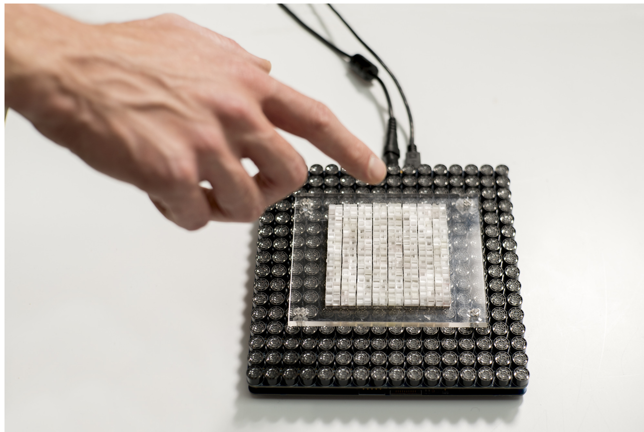

Figure 1. Haptic demonstration: A haptic sensation is created at the focal point.

The focal point achieved with a metasurface is the same quality as when using the Ultrahaptics board alone. It's also possible to achieved a sub-wavelength focus with a meta-surface, compared to at least a wavelength diameter focus with the board alone.

Although the demonstration uses proprietary hardware, the same effect can be replicated with, for example, a single 40kHz speaker (point source) and an additional, complementary phase distribution.

Auditory Demonstration

Context

This demonstration makes use of a Holosonics Audio Spotlight - a directional speaker [4]. The speaker transmits at an ultrasonic frequency of approximatively 64kHz. The modulating wave of the audio is offset from the carrier wave, which is demodulated once it hits a solid object (such as the human ear).

Procedure

This demonstration alters the direction of the beam created by the parametric speaker. When a specifically ordered metasurface is placed in front of the speaker, it acts as a diffraction grating, causing interferences which bend the beam of sound in a new direction. The angle chosen for this demonstration was taken from a quantised range of possible angles.

Graphical User Interface (GUI)

We will also be demonstrating an end-user program with a GUI for specifying either focal points or beam angles from which lenses and grates are generated programmatically.

Applications

There are many applications of acoustic field distribution. In High Frequency Focused Ultrasound (HIFU), for example, sparse arrays of transducers are used to treat a variety of tumours or functional brain disorders, inducing a localised heating effect, even behind the ribs. In industrial applications, focusing and steering of ultrasonic waves is required to find small cracks in metallic components, which can be complex in geometry and highly anisotropic. New applications that require precise control of acoustic waves include parametric loudspeakers, ultra-haptics and acoustic levitation.

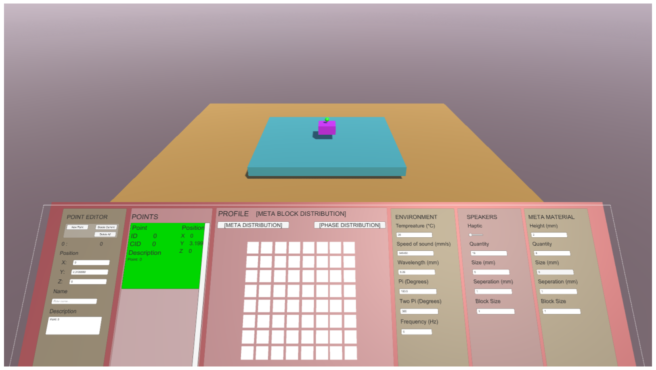

Figure 3. GUI: A screenshot of a draft version of the end-user program.

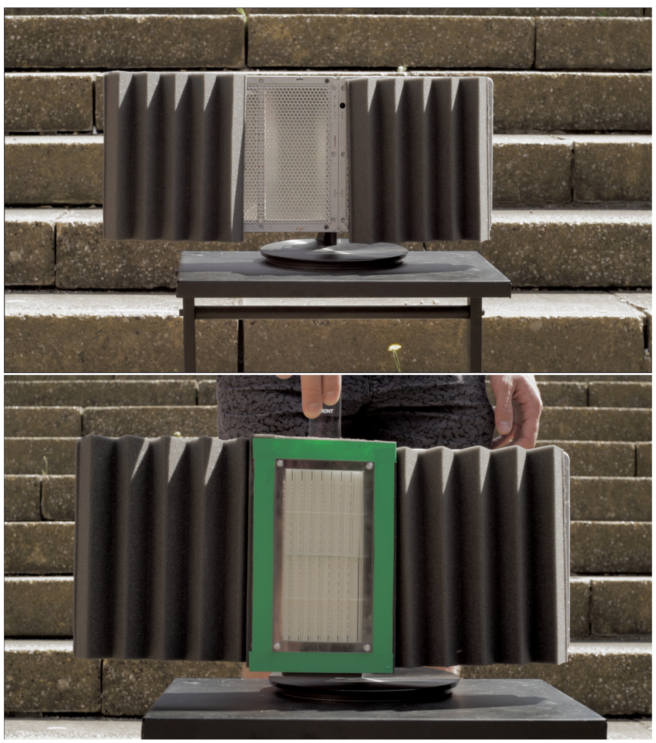

Figure 2. Auditory demonstration: The speaker's beam of sound is diverted by the metasurface.

Future

Acoustic metamaterials allow us to shape the sound-field in a way that is akin to how LCDs and projectors shape light. One source of light passes through an array of pixels, with each pixel letting through a specific amount of light. The current situation in sound control is with each unit of the array creating it's own pressure using transducers. This requires complex, real-time processing, which most manufacturers would choose to avoid. Transmissive Metamaterials that can be programmatically controlled can allow us to shape an output sound field starting from a single source of sound waves.

Each metamaterial brick can be made of flaps that could open or close allowing us to dynamically change the introduced phase delay. The device can then be controllable software controlled, allowing the creation of any sound field geometry to be created on the fly using established techniques [2].

References

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